ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 7, April 2016

Detection of Power Quality Disturbances Using Wavelet Transform Analysis

S.Edwin Jose [1], S.Titus[2]

Asst. Professor, Dept. of EEE, Raajas Engineering College,Vadakkankulam, Tamil Nadu, India[1]

Professor & HOD, Dept. of Electrical and Electronics Engineering, M.A.M College of Engineering, Trichy, Tamil Nadu, India[2]

ABSTRACT: The algorithm to detect power quality disturbances using Stationary Wavelet Transform (SWT) was developed and presented in this paper. The prime advantage of the SWT based algorithm is restoring of the time (or translation) invariance property that is lost in conventional methods. The disturbed signals was decomposed into many frequency sub-bands in frequency domain where the disturbing time and the level were identified. The simulation was carried out using MATLAB and the comparative analysis was done for different 8 parted signals using various wavelet transforms. The developed SWT algorithm is found to provide more accurate solution for detection of disturbances.

KEYWORDS: Digital signal processors, MATLAB, Power Quality, Wavelet transforms.

I. INTRODUCTION

In the recent years, the demand for the quality power supply has increased for various electrical applications. This has motivated many researchers to work to deliver clean power to the customers in the presence of distorted wave forms. A power quality problem can be described as any variation in the electrical power service, such as voltage dips, voltage sag, momentary interruptions, harmonics, transients, notches, and noises resulting in failure of end-use equipment.

Identification and classification of voltage and current disturbances in power systems is an important task in power system monitoring and protection. The power quality mitigations are feasible only after the accurate detection of the disturbances. Recent advances in the wavelet transforms are found to be a powerful tool for power quality analysis. Traditionally, the wavelet transform (WT) has been successfully used for representing and analyzing non-stationary signals in many electric power system applications [1]. The WT was used effectively in a number of situations, to represent natural, highly transient phenomena that result from a dilation and shift of the original waveform.

Shilong Wu et al [2] represents a powerful signal processing with a wide variety of applications; more specifically for the analysis of non-stationary signals [2-3]. In wavelet analysis, the wavelet function is compared to a section of the signal under study. Obtaining a set of coefficients that represent how closely the wavelet function with the signal is the crux. WT offers good time resolution and poor frequency resolution at high frequencies, and good frequency resolution and poor time resolution at low frequencies. This approach makes is applicable only when the signal has high frequency components for short durations and low frequency components at long durations. The computational speed for the FFT is $n\log_2 n$ while for the DWT, it is only 'n'. This means less memory size needed and high computational speed [4-5]. Although the time and frequency resolution problems are the results of a physical phenomenon and exist regardless of the transform used, it is possible to analyze any signal by using an alternative approach called Wavelet Packet Transform (WPT). In WPT, the details as well as the approximations can be split and WPT analyses the signal at different frequencies with different resolutions [6]. But in many cases, the extracted wavelet features are not optimal to deal with the time and frequency ranges of power quality events [7].

The stationary wavelet transform (SWT) has been recently applied for solving many signal and image processing problems [8]–[11]. In 1996, SWT was first introduced to restore the time (or translation) invariance property that was lost in the DWT [12]-[14]. The effect of lacking this property is that the coefficients of translated signal are not a time-shifted version of those of the original signal which is the case in the non redundant transform as in the DWT. Although the performance of the non redundant transform-based algorithms are very fast due to the multiresolution analysis

(MRA) provided [15], redundancy usually facilitates the identifications of certain properties associated with non stationary signals, such as fast or rapid changes and transients..

In this paper, a modified algorithm is proposed to detect power quality disturbances for different types of power quality signals. The time and energy analysis can be carried out from approximation coefficients. The aliasing present in DWT can be restored using Lifting Wavelet Transform (LWT). This ensures perfect reconstruction of the signal and the lack of time invariance property in LWT can be restored by up sampling the filter coefficients in SWT. The comparison of the performance of the results obtained from Wavelet Packet Transform (WPT), Lifting Wavelet transform (LWT) and Stationary Wavelet Transform (SWT) for different test signals are carried and presented .

II. POWER QUALITY ESTIMATION USING WAVELET TRANSFORM

The stationary wavelet transform (SWT) was recently applied for solving many signal problems and introduced to restore the time (or translation) invariance property that was lost in conventional methods [16]. The redundancy can also be restored by replacing the down sampling process of the coefficients by up sampling in the DWT. The SWT algorithm is shown in Figure.1

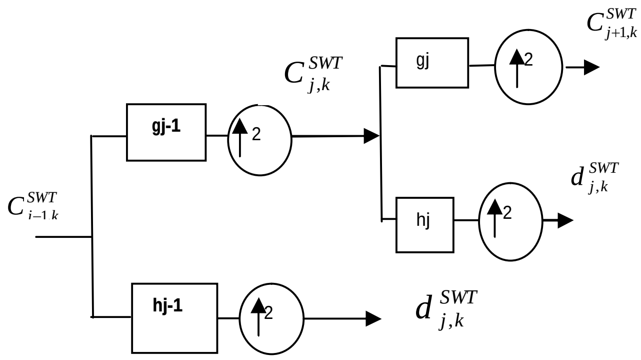


Figure.1 Schematic representation of Stationary Wavelet Transform

The effect of the down sampling involved in the DWT is to reduce the length of the coefficients by a half after each decomposition level of the signal. This means less coefficients are being processed which reduces the memory size and speeding up the process of extracting the approximations and the details. However, this comes at the expense of losing the time invariance property which is associated with redundant algorithms. The importance of the time-invariance property is to help to identify and detect the fast or rapid changes, transients, and other time varying signal characteristics [17]. The translated signal is the same as the translated version of the transformed signal, which ensures the time-invariance property.

This time-invariance property can be restored just by simply upsampling the filter coefficients as shown in fig.1 instead of downsampling the extracted DWT coefficients. The resulting algorithm is of the redundant type and is called the stationary wavelet transform (SWT). The approximation and detail SWT coefficients can be expressed as [18]

$$C^{SWT}_{j,k} = \sum_m C^{SWT}_{j-1,k+2^{j-1}m}\, g(m) \tag{1}$$

$$d^{SWT}_{j,k} = \sum_m C^{SWT}_{j-1,k+2^{j-1}m}\, h(m) \tag{2}$$

Here,

C is the scaling coefficient

$C^{SWT}_{j,k}$ is the approximation coefficient

$d^{SWT}_{j,k}$ is the detailed coefficient

m= 1,….J is any arbitrary integer.

The developed power quality components can be obtained from eq.(1) and (2) using SWT . The rms voltage and current can be expressed as

$$V^{SWT} = \sqrt{\frac{1}{T}\sum_{k}\left[C_{j0,k}^{(v)SWT}\right]^2 + \frac{1}{T}\sum_{j\geq j0}\sum_{k}\left[d_{j,k}^{(v)SWT}\right]^2}$$
$$= \sqrt{\left[V_{j0}^{SWT}\right]^2 + \left[\sum_{j\geq j0} V_{j}^{SWT}\right]^2}$$
$$= \sqrt{\left[V_{A}^{SWT}\right]^2 + \left[V_{D}^{SWT}\right]^2} \qquad (3)$$

$$I^{SWT} = \sqrt{\frac{1}{T}\sum_{k}\left[C_{j0,k}^{(i)SWT}\right]^2 + \frac{1}{T}\sum_{j\geq j0}\sum_{k}\left[d_{j,k}^{(i)SWT}\right]^2}$$
$$= \sqrt{\left[I_{j0}^{SWT}\right]^2 + \left[\sum_{j\geq j0} I_{j}^{SWT}\right]^2}$$
$$= \sqrt{\left[I_{A}^{SWT}\right]^2 + \left[I_{D}^{SWT}\right]^2} \qquad (4)$$

Where $V_A^{SWT}, V_D^{SWT}, I_A^{SWT}, I_D^{SWT}$ are the approximation and detail voltage and current rms values in the SWT domain. The approximation voltage and current are extracted at level j_0 (lowest frequency band), while the detail voltage and current are extracted at levels $j \geq j_0$ using the voltage and current SWT coefficients as defined in (2) and (3). The approximation active power in the SWT domain can be defined as

$$P_A^{SWT} = P_{j0}^{SWT} = \frac{1}{T}\sum_{k} C_{j0,k}^{(v)SWT}\, C_{j0,k}^{(i)SWT} \qquad (5)$$

and the detail active power is given by

$$P_D^{SWT} = \sum_{j\geq j0} P_j^{SWT} = \frac{1}{T}\sum_{j\geq j0}\sum_{k} d_{j,k}^{(v)SWT}\, d_{j,k}^{(i)SWT} \qquad (6)$$

Then the total active power transferred can be the algebraic sum of the approximation and detail active powers and is given as

$$P^{SWT} = P_A^{SWT} + P_D^{SWT} \qquad (7)$$

By applying the Parseval's theorem to the SWT, the energy levels from the detailed coefficients can be represented as

$$\frac{1}{N}\sum_{k=1}^{N}\left|f(k)\right|^2 = \frac{1}{N}\sum_{k=1}^{N}\left|a_j(k)\right|^2 + \sum_{J=1}^{J}\left(\frac{1}{N}\sum_{k=1}^{N}\left|d_j(k)\right|^2\right) \qquad (8)$$

From equation (8), it can be understood that the average power of the approximated version of the decomposed signal is denoted by the first term and the detailed version of the decomposed signal is denoted by the second term. The energy distribution features of the detailed coefficients of distorted signal will be employed to extract the features of power disturbances. The energy of the distorted signal can be decomposed at different resolution levels in different ways depending on the power quality problem. Therefore, a N-level decomposition of each discrete distorted signal will be performed to obtain the detailed version coefficients which will extract the features of the distorted signal for classifying different power quality problems. The process can be represented mathematically by

$$P_J = \frac{1}{N}\sum_{k=1}^{N}\left|d_J[k]\right|^2 = \frac{\left\|d_J\right\|^2}{N} \qquad (9)$$

Where $\|d_J\|$ is the norm of the expansion coefficient d_J .

The flow chart of the proposed method is shown in figure.2

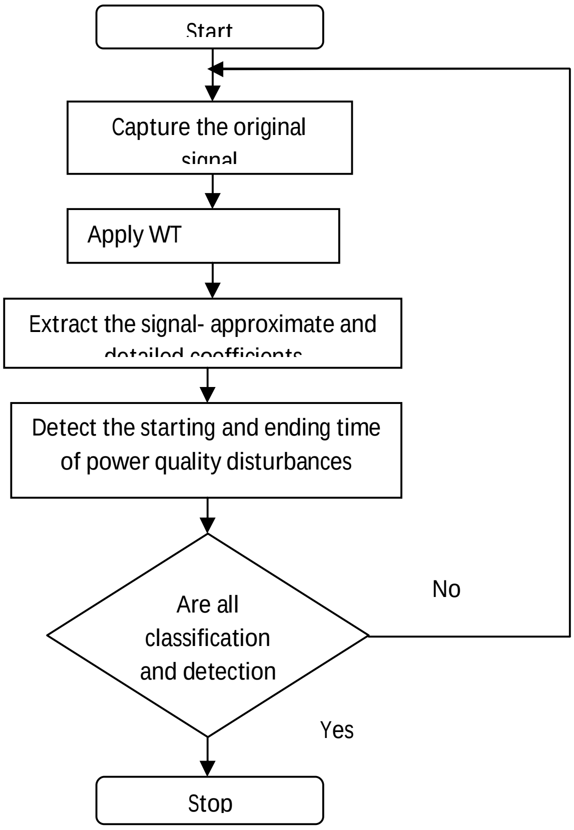


Fig.2 Flow Graph of the developed PQ disturbance detection Algorithm

III. RESULTS AND DISCUSSION

The standard disturbances such as voltage dips or sags, voltage swells, interruptions, harmonics and oscillatory transients are considered for the present analysis. The case studies include both stationary and nonstationary PQ disturbances. The developed SWT algorithm was tested using the simulated and actual field data for various disturbances. The diagram of the circuit for the simulations in MATLAB- SIMULINK is given in Figure. 3.

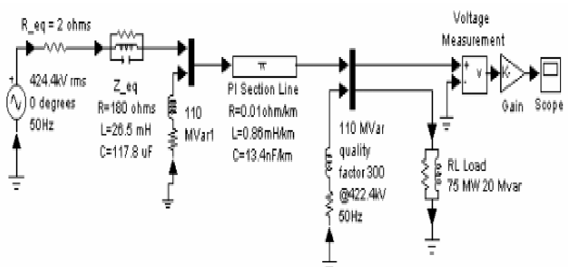


Fig.3 MATLAB SIMULINK model of the disturbance detection system

The developed algorithm is compatible with the detection of different power quality disturbance groups. The Daubechies 4 wavelet function and the filter bank with ten levels of decomposition are used in this algorithm. The

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 7, April 2016

sampling frequency is selected as 1.6 KHz with fundamental frequency of 50 Hz. The SWT techniques for detecting the power quality disturbances are implemented using the software package of MATLAB. The tested disturbance signals are generated using MATLAB using standard IEEE bus data model as shown in fig 4.

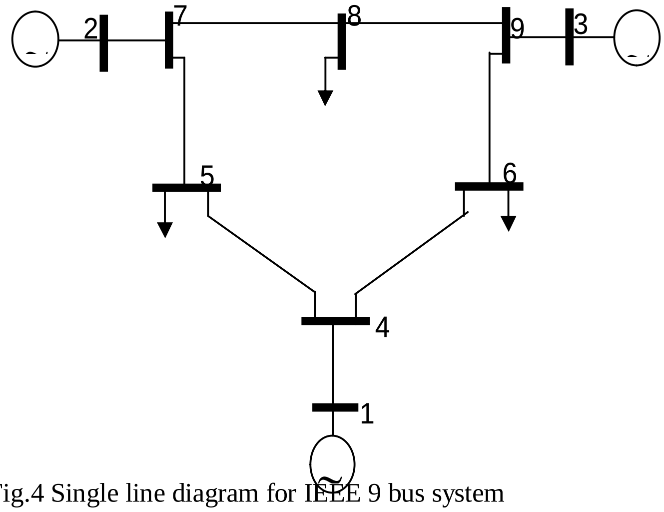
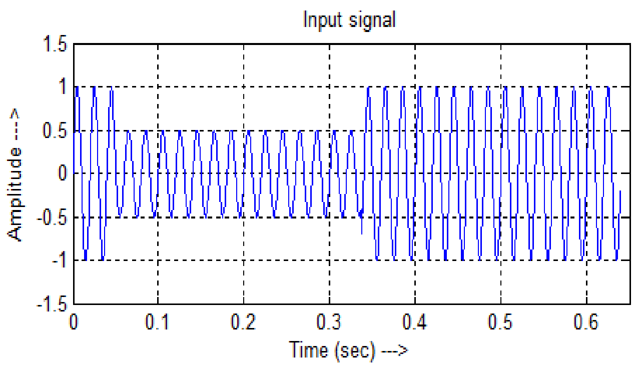


Fig.4 Single line diagram for IEEE 9 bus system

The energy levels of detailed coefficients at each level is obtained from equation (9). This is very much useful for classification of power quality disturbances. Comparative studies of the performance of the proposed and conventional method are carried out under different conditions.

A. VOLTAGE SAG

A PQ detection system is often essential to capture the occurrence of the voltage sag disturbances in order to find possible solutions for the problem. The input signal and the simulation results of the proposed wavelet transforms are shown in Figure 5. Figure. 5(a) shows a simulated voltage sag signal caused by increasing the load for five cycle duration and then switching it back to low noise signal. A fluctuating signal is not a complete interruption of power and voltage sags.



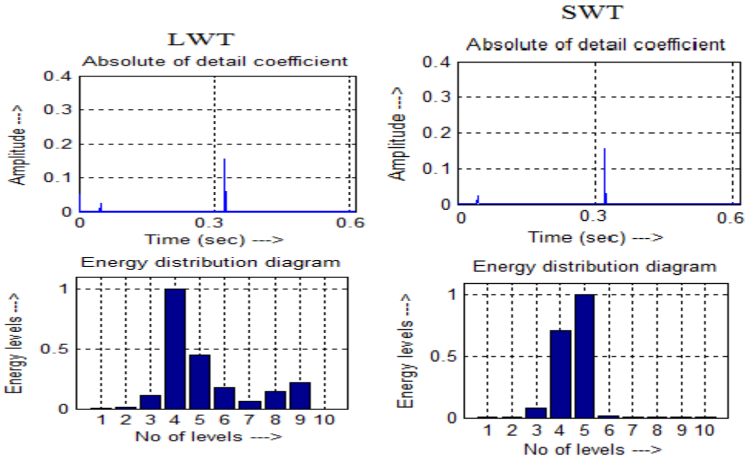
(a)

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 7, April 2016



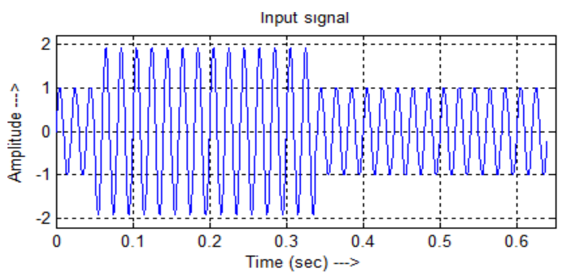
(b) *(c)*

Fig.5.(a) Sag Signal (b) Output of LWT (c) Output of SWT

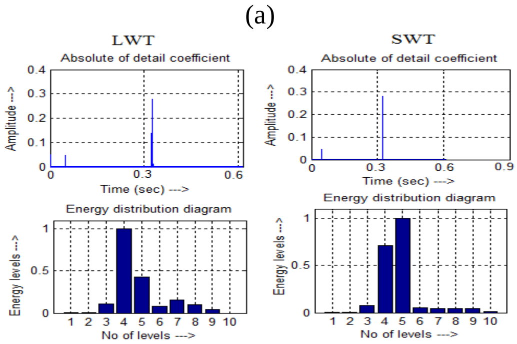
When the load is increased, the disturbance is detected from 0.05025sec to 0.3517sec. The energy distribution diagram gives energy pattern which will be used for automatic detection. The computation time and the location of disturbance starting and ending time with percentage deviation are also estimated. It is clear from the figures 5(b) and 5(c) that the SWT introduce less deviation while compare to WPT and LWT. The SWT based approach gives lesser computation time.

B. VOLTAGE SWELL

When the normal voltage increases by 10 to 90 percent, voltage swell occurs. It is shown in Figure 6.



(a)



(b) *(c)*

Fig.6.(a) Swell signal (b) Output of LWT (C) Output of SWT

The PQ disturbance detection and energy distribution give enough information for better detection and classification. The location of disturbance starting and ending times are 0.05025sec and 0.3517sec respectively. As expected, the

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

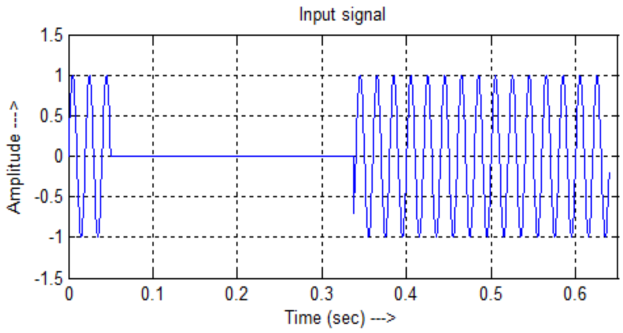
(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 7, April 2016

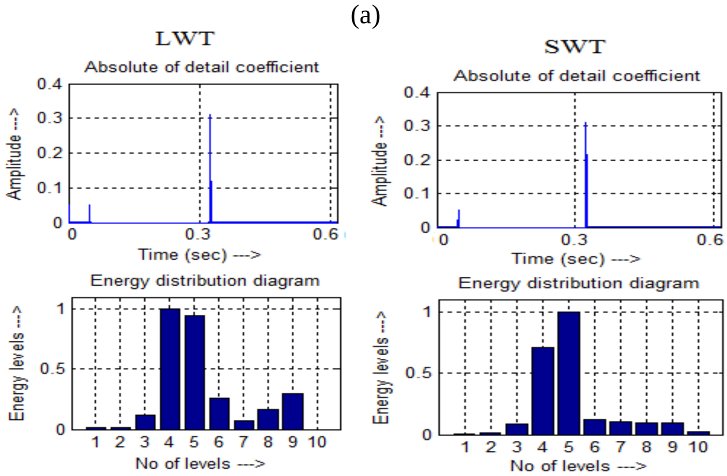
values of the power components obtained using the SWT are less in error and better result while compare to other transforms.

C. INTERRUPTIONS

The interruption can be seen as a momentary loss of voltage in a power system. Such disturbance occurs due to a drop of 90 to 100 % of the rated system voltage. The disturbance starting and ending time is measured from the absolute value of detail coefficients as shown in Figure 7 and error is also compared.



(a)

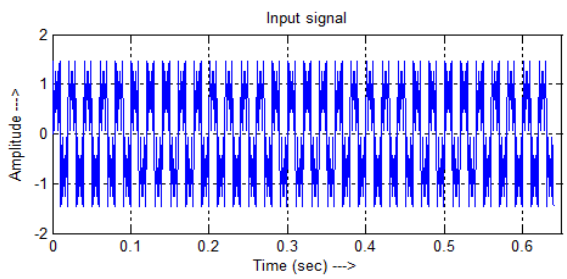


(b) *(c)*

Fig.7.(a)Interruption (b)output of LWT(c)Output of SWT

D. HARMONICS

The presence of harmonic distorts the shape of the voltage and current which in turn creates many problems resulting in misoperation or failure of end-use equipment. The input signal and the simulation results for different wavelet transform are shown in Figure 8.



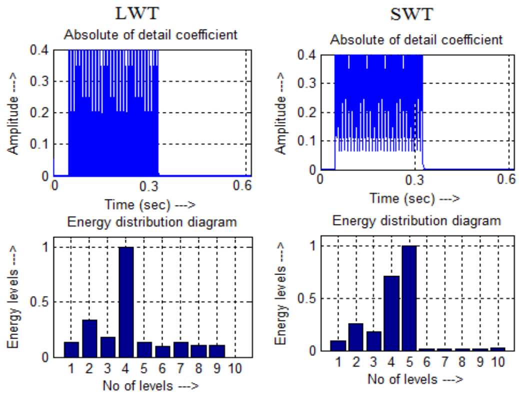
(a)

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 7, April 2016



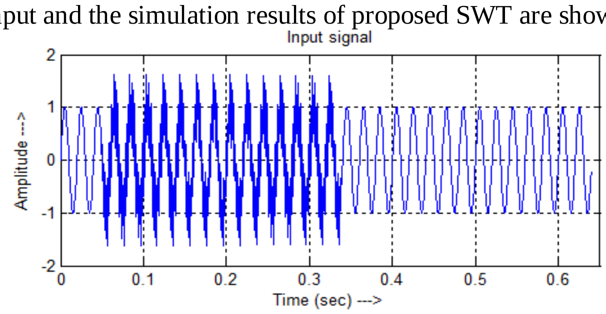
(b) *(c)*

Fig.8.(a) Harmonics (b) Output of LWT (c) Output of SWT

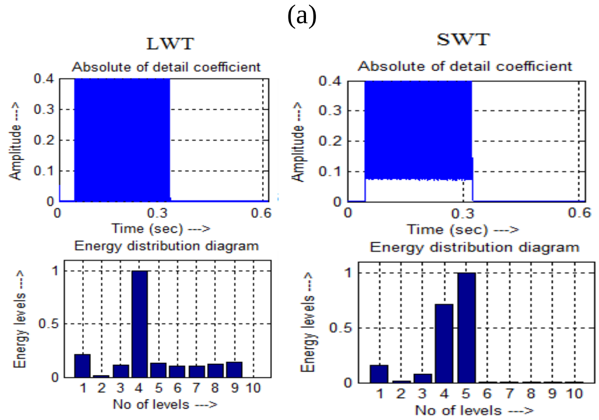
The location of disturbance starting and ending time is shown in Table 2 with percentage deviation and the energy levels in each detailed signals are calculated using Parseval's theorem. The SWT approach obviously detect the PQ disturbance even high order harmonics is present in the input signal. The error is also less in the proposed method.

E. OSCILLATORY TRANSIENTS

The power quality disturbance which lasts for a time duration shorter than sags or swells is called oscillatory transients which are given as input and the simulation results of proposed SWT are shown in Figure 9.



(a)



(b) *(c)*

Fig.9.(a) Oscillatory Transients(b)Output of LWT c)Output of SWT

The disturbance starting and ending time which is measured from the absolute value of detail coefficients by signal decomposition of input signal are shown in Table 1 with percentage deviation.The comparison of computation time in various transform is shown in Figure 10.From the results obtained, it is found that SWT has better performance than LWT and WPT. Figure 10 shows the total computation time for the analysis of power quality disturbance.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 7, April 2016

TABLE I COMPUTATION TIME FOR DIFFERENT CONDITIONS USING DB4 WAVELET FUNCTIONS

Type of disturbances	Computation time(sec)		
	WPT	LWT	SWT
Voltage Sag	1.2804	0.6674	0.5927
Voltage Swell	1.2517	0.6751	0.5921
Interruptions	1.3259	0.6789	0.6095
Harmonics	1.3543	0.6675	0.5923
Oscillatory Transients	1.4732	0.6841	0.5916

TABLE II PERCENTAGE DEVIATION FOR DIFFERENT CONDITION USING DB4 WAVELET FUNCTIONS

Type of disturbances	Disturbance Time (sec)				Deviation (%)		
	Theoretical	WPT	LWT	SWT	WPT	LWT	SWT
Voltage Sag	t1=0.05 (starting time)	t1=0.05 035	t1=0.05 025	t1=0.05 017	0.69	0.49	0.33
	t2=0.35 (Ending time)	t2=0.35 24	t2=0.35 17	t2=0.35 12			
Voltage Swell	t1=0.05	t1=0.05 037	t1=0.05 025	t1=0.05 016	0.73	0.49	0.32
	t2=0.35	t2=0.35 25	t2=0.35 17	t2=0.35 11			
Interruptions	t1=0.05	t1=0.05 024	t1=0.05 014	t1=0.05 005	0.47	0.28	0.11
	t2=0.35	t2=0.35 16	t2=0.35 10	t2=0.35 04			
Harmonics	t1=0.05	t1=0.05 016	t1=0.05 009	t1=0.05 005	0.32	0.18	0.11
	t2=0.35	t2=0.35 11	t2=0.35 06	t2=0.35 04			
Transients	t1=0.05	t1=0.05 020	t1=0.05 012	t1=0.05 007	0.41	0.24	0.14
	t2=0.35	t2=0.35 14	t2=0.35 08	t2=0.35 05			

WPT consumes more time; SWT is faster than any of the transforms and the techniques are compared at different disturbance conditions with error comparison graph shown in Figure 10.

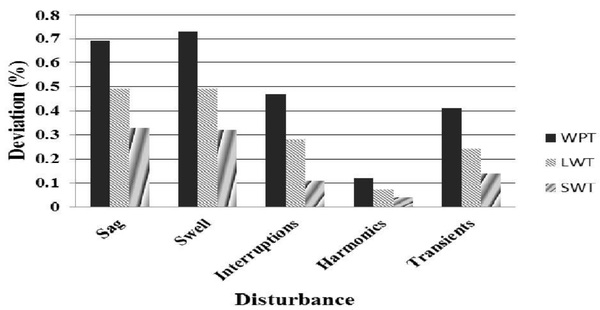


Fig.10 Percentage of Deviation with various disturbance for different WT

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 7, April 2016

IV. CONCLUSION

The analysis of power quality disturbance using db4 wavelet function for various disturbances are carried out and presented. Several case-studies, related to the most common disturbances in electrical power quality analysis, have shown the suitability of the developed approach. The performance of the developed method has been compared with the results obtained using conventional technique for different measurement conditions. The results show that SWT is more accurate and give better results in detecting power quality disturbance.

REFERENCES

1. EnrangZheng, Zhengyan Liu, Lingkum Ma,"Study on Harmonic Detection method based on FFT and Wavelet Transform", 2nd International conference on signal processing systems ICSPS) ., vol.3,July 2010.
2. Shihong Wu, Zailin Piao, Jianweiji, Xiaoliang Li, ; "Harmonics Detection in Electric Power System Based on Wavelet packet Transform", International conference on intelligent computation Technology and Automation. , vol.2, May 2010.
3. W. G. Morsi and M. E. El-Hawary,"Reformulating three-phase power components definitions contained in the IEEE standard 1459-2000 using discrete wavelet transform,"IEEE Trans. Power Del., vol. 22, no. 3, pp. 1917–1925, Jul. 2007.
4. S. Santoso, E. J. Powers, W. M. Grady, and P. Hofmann, "Power quality assessment via wavelet transform analysis," IEEE Trans. Power Del., vol. 11, no. 2, pp. 924–930, Apr. 1996.
5. Kocaman, Ozdemir.M, "Comparison of statistical methods and wavelet energy coefficients for determining two common PQ disturbances: Sag and Swell", IEEE International conference on Electrical and Electronics Engineering, pp1-81-1-84,Nov 2009.
6. Chen Chun-ling, Xu Tong-Yu, Yuan Ye, Jiang Fengli, "Detection and Location of Power Quality Transient Disturbance Based on Lifting Wavelet", IEEE conference on power and Energy, pp 1-4,Mar. 2010.
7. Min Li Guang-pu He, Xiao-ying Zhang, Xiao-hong Wu,"power Quality Detecting based on Fast Lifting Wavelet Transform", IEEE conference on power and Energy, pp 536-540, jul 2008.
8. Walid.G.Morsi and M..E.El-Hawary,"A New Perspective for the IEEE Standard 1459-2000 Via Stationary Wavelet Transform in the Presence of Nonstationary Power Quality Disturbance", IEEE Trans. Power Del., vol. 23, no. 4, pp. 2356–2365,Oct. 2008.
9. Hao Ye, Guizeng. Wang, and Steven. X. Ding,"A new fault detection approach based on parity relation and stationary wavelet transform,"in Proc. Amer. Control Conf., Jun. 2003, pp. 2991–2996.
10. K. V. Kale, R. R. Manza, S. S. Gornale, P. D. Deshmukh, and V. Humbe,"SWT based composite method for fingerprint image enhancement,"in Proc. IEEE Int. Symp. Signal Processing Information Tech-nology, Aug. 2006, pp. 162–167.
11. S.Edwin Jose,S.Titus,"Detection and Recognition of Power Quality Disturbances using Lifting Wavelet Transform", IASTED International Conference Engineering and Applied Sciences (EAS 2012) Colombo,Srilanka Dec.2012.
12. J. C. Pesquet, H. Krim, and H. Carfantan,"Time-invariant orthonormal wavelet representations,"IEEE Trans. Signal Process., vol. 44, no. 8, pp. 1964–1970, Aug. 1996.
13. Hao Ye, Guizeng Wang, and Steven X. Ding, "A New Parity Space Approach for Fault Detection based on Stationary Wavelet Transform",IEEE Transactions on Automatic Control,Vol.49,No.2, Feb 2004.
14. OmerNeiih Grerek,Ece and Dogan Gokhan, "An Adaptive statistical Method for power Quality Analysis ", IEEE Transactions on Instrumentation and measurement, vol.54, No.1, Feb 2005
15. Julio Barros and Ramon E. Diego, "Application of the wavelet packet Transform to the estimation of Harmonic Groups in current and voltage waveforms",IEEE Transactions on power delivery,vol.21,No.1, Jan 2006
16. Cho Soo-Hwan,Gilsoo Jang; and Sae-Hyuk Kwon ,"Time frequency Analysis of Power Quality Disturbances via the Gabor-Winger Transform",IEEE Transactions on Power delivery,vol.25,No.1,Jan 2010.
17. Solbo.S and Eltoft.T, "A stationary wavelet-domain Wiener filter for correlated speckle," IEEE Trans. Geosci. Rem. Sens., vol. 46,No.4, pp. 1219–1230, Apr. 2008.
18. Z.Gaing,"Wavelet-based neural network for power disturbance recog-nition and classification,"IEEE Trans. Power Del., vol.19,no.4,pp.1560-1568,Oct.2004.